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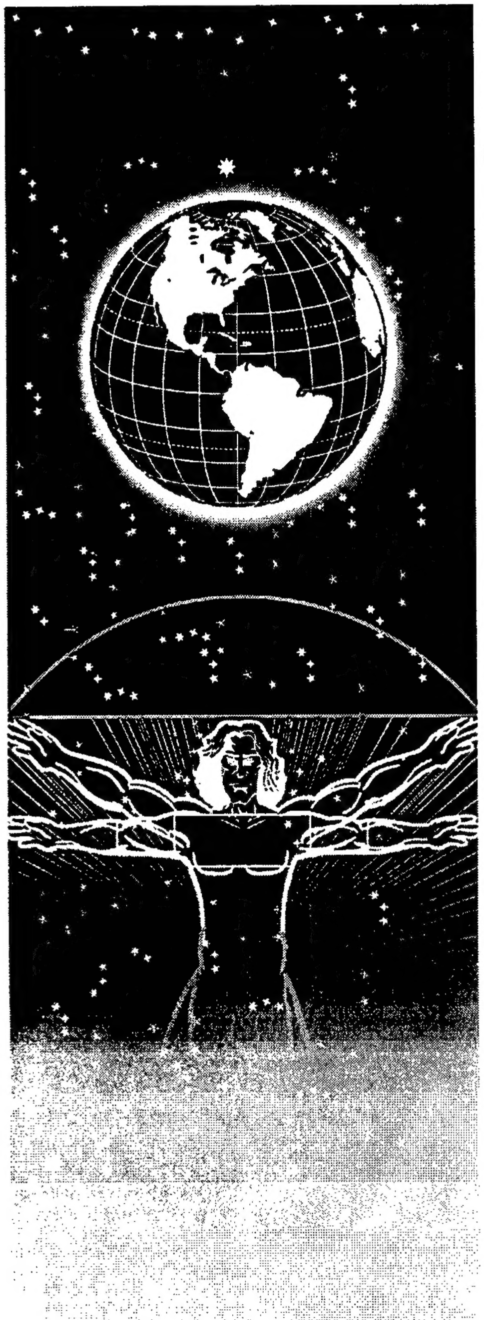

UNITED STATES AIR FORCE RESEARCH LABORATORY

SPATIAL RESOLUTION OF TWO, HIGH LINE-RATE, MONOCHROME DISPLAY SYSTEMS

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13. ABSTRACT *(Maximum 200 words)*

This report describes an evaluation of the spatial resolution of two, high line-rate display systems each consisting of the same graphics board but a different monochrome CRT monitor. Given that increasing the line rate of a display does not necessarily increase its spatial resolution, an evaluation of this kind is required to determine the minimum line rate needed to support the training of a given visual task.

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SPATIAL RESOLUTION OF TWO, HIGH LINE-RATE, MONOCHROME DISPLAY SYSTEMS

BACKGROUND

Current flight simulators have display systems whose line-rates (or number of displayed pixels) are below those required to support the training of many low-level flight and air-to-air tasks.

In the context of visual displays, eye-limited resolution is generally considered to be approximately one minute of arc. For a viewing distance of one meter, this would correspond to a resolvable line pair of about 0.3 mm. Display line-rates that provide line pairs of this magnitude are currently available from monochrome monitors used for medical imaging. The line rates provided by these monitors are similar to those expected to be provided by the latest generation of laser projectors being evaluated by the Air Force Research Laboratory, Human Effectiveness Division, Warfighter Training Research Division (AFRL/HEA).

We describe here an evaluation of the spatial resolution of two, high line-rate display systems each consisting of the same graphics board but a different monochrome CRT monitor. Monitor "line-rate" is often the only available measure of "spatial resolution," but these are not equivalent terms. We have applied spatial resolution evaluation criteria, similar to those suggested by the Video Electronics Standards Association (VESA), to two monitors with the same line-rate. Significant differences were found between the monitors, indicating that an objective criterion is required to properly evaluate monitors with the same line-rate.

METHOD

Apparatus

The two monitors evaluated were monochrome white (P45 phosphors) and had 2560 (H) × 2048 (V) addressable pixels over an active video area of about 360 mm (H) × 290 mm (V). A DOME Imaging Systems imaging board (Model Md5/PCI) was used to drive both monitors. The DOME board could only be used under Microsoft Windows NT, which apparently limits addressing under DirectDraw to images no larger than 2048 × 2048.

Spatial luminance measurements were made using either a Photo Research Model 1500 Spectra SpotMeter (for the gamma functions), or a Photo Research Model PR-719 Spot Spectrascan Fast Spatial Scanner (for the spatial resolution functions). The SpotMeter and Spatial Scanner had measurement apertures of 0.5° diameter and 1.5° × 0.5°, respectively. Measurements were made on 2048 × 2048 test images generated using a program (*TPattWiz.exe*) provided by DOME Imaging Systems. The installation file (*TestPattWizard.ZIP*) was downloaded from DOME's technical support site (*ftp://ftp.dome.com/pub/*). The test stimuli used were either of a single grayscale value, or were grille patterns composed of alternating black (grayscale = 0) and white (grayscale = 255) lines of various widths. The lines were either horizontal or vertical and were 1, 2, 3, or 4 pixels wide.

Temporal luminance measurements were made using the analog output of the Spectra SpotMeter, and imagery generated by a program (provided by E. Moreno, Boeing Co.) written under DirectDraw. The program alternated a 2048 × 2048 image between graylevels of 0 and 255 at the maximum rate allowed by the DOME imaging board.

Procedure

Each monitor was evaluated as configured by the manufacturer. The minimum (image grayscale = 0) and maximum (image grayscale = 255) luminances were adjusted using various brightness and contrast controls available on each monitor. The minimum luminance was set to 0.05 fL for Monitor A and to 0.01 fL for Monitor B. The higher value was required for Monitor A due to the design of its internal calibration system. The minimum levels for each monitor were clearly visible in a dark room after 5-10 min of dark adaptation. In addition, it was determined that increasing the minimum luminance of Monitor B to 0.05 fL did not significantly change the estimated spatial resolution. The maximum luminance was set to 32 fL for each monitor.

Gamma functions were measured for each display system by measuring the luminance of a 2048 × 2048 image set to various grayscale values between 0 and 255. These measurements were made at the center of the monitor screen using the SpotMeter.

Spatial resolution was estimated from *luminance distributions* obtained by sampling a small portion of both the horizontal and vertical grille patterns at 115 points near the center of the display. Measurements were also made, for the vertical grille patterns only, at a point located two-thirds of the distance from the center of the display to its lower right corner. The maximum (L_{max}) and minimum (L_{min}) luminances for a black/white line-pair located near the center of the distribution were then estimated, and the *percent contrast modulation* was calculated as $[(L_{max} - L_{min}) / (L_{max} + L_{min})] \times 100$. Finally, the grille pattern width that corresponded to a contrast modulation of 25% was interpolated from the plotted values.

The temporal characteristics of the display system were evaluated by measuring the luminance of the alternately displayed black-and-white images using the analog output of the SpotMeter displayed on an oscilloscope.

RESULTS

Display System Gamma Functions

Gamma functions representing measured luminance as a function of grayscale value for each of the display systems (imaging board + monitor) are shown in Figure 1. The power function that best fits these data has an exponent of approximately 3.2, and is also shown (suitably scaled) in Figure 1. Interestingly, a power function with an exponent of 3.2 is very nearly the inverse of the power function that relates perceived brightness to stimulus luminance (exponent ≅ 0.33). Thus, perceived brightness can be assumed to increase approximately linearly with grayscale value for the display systems evaluated here.

Display System Spatial Resolution

Figure 2 shows the estimated contrast modulation plotted as a function of grille line width for the various measurement conditions considered here. The data shown in the top graph are for vertical lines (i.e., representing horizontal resolution) at the center of the display, and indicate that Monitor A produced slightly greater image contrasts for three of the four grille patterns tested. The data shown in the center graph indicate that Monitor A produced much higher image contrasts for horizontal lines at the center of the display. Finally, the data in the bottom graph indicate that Monitor A produced higher contrasts for vertical lines near the lower right corner of the display.

The high image contrasts shown by Monitor A were related to a small raster spot size that could only be maintained for moderately low peak luminance levels. Because of this small spot size, individual raster lines were visible within the white areas of the test grilles composed of lines more than 1 pixel wide (i.e., greater than 1 on / 1 off). This places a lower limit of about two feet on the viewing distance at which the specified spatial resolution of Monitor A is valid.

Effective Resolution (Resolvable Pixels)

Following the VESA standard (*VESA, Flat Panel Display Measurements Standard, Version 1.0, May, 1998*), we define effective resolution as the number of addressable pixels that can be resolved at a given contrast modulation criterion. Effective resolution was calculated by dividing the number of addressable pixels (2560 horizontal or 2048 vertical) by the grille line width (in pixels) corresponding to a contrast modulation of 25 % (see Figure 2). The calculated number of resolvable lines (NRLs) is shown in Table 1 for each measurement condition.

Temporal Characteristics

The maximum frame rate estimated for both display systems was 5-6 frames/sec. Due to limitations in DirectDraw as run under Windows NT, the temporal response could only be evaluated for a 2048 × 2048 image.

CONCLUSIONS

For imagery presented at the center of the screen, Monitor A was found to produce about 1.1 times (2560 vs. 2306) as many resolvable vertical lines and 3.3 times (5785 vs. 1736) as many resolvable horizontal lines as Monitor B. For imagery presented at the corner of the screen, Monitor A produced about 1.5 times (3200 vs. 2116) as many resolvable vertical lines.

The monitors tested are capable of producing luminances of over 100 fL, whereas the current evaluation was performed at a maximum luminance of about 32 fL. The much higher vertical resolution of Monitor A appears related to a small raster spot size that presumably would increase with display luminance. Thus, it is possible that the raster spot size of Monitor B could be adjusted to increase its spatial resolution, especially in the vertical direction.

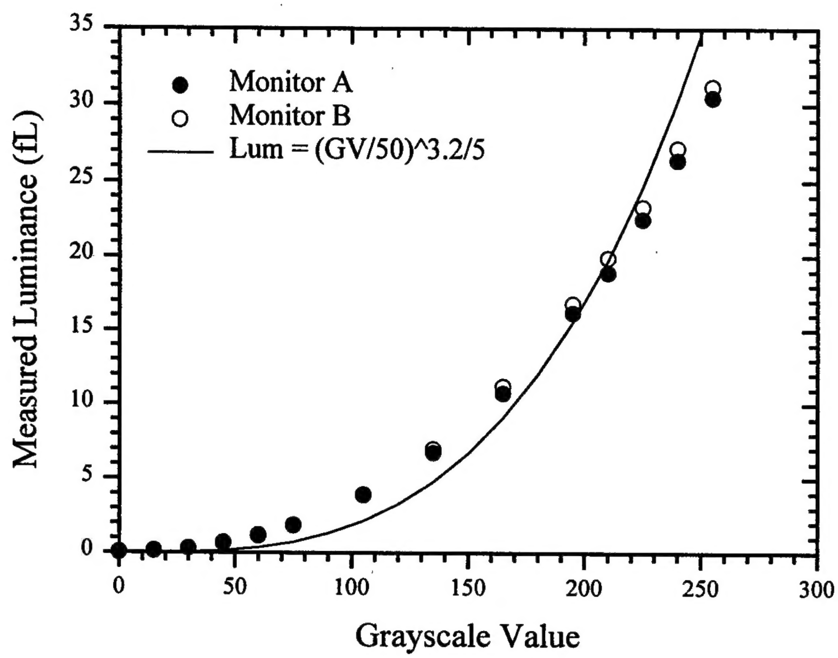

Figure 1. A comparison of the measured gamma functions obtained for the two display systems evaluated

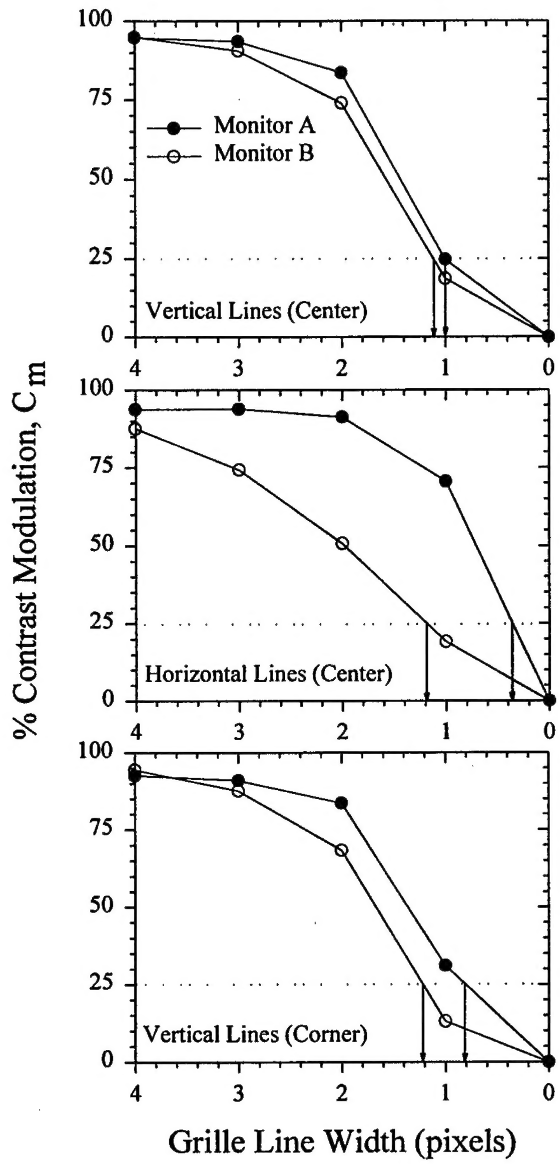

Figure 2. Measured C_m plottted as a function grille line width. The dotted line indicates a C_m criterion of 25 %.

Table 1

Summary of Measured Maximum and Minimum Luminances, Calculated Contrast Modulations (C_m), Estimated Criterion Grille Line Width (CGLW), and Estimated Number of Resolvable Lines (NRLs) for Each Display and Each Measurement Condition. Each Display had 2560(H) x 2048(V) Addressable Lines.

		Vertical Lines (Center)			Horizontal Lines (Center)			Vertical Lines (Corner)		
	GLW (pixels)	Max./Min. Luminance (fL)	C_m	CGLW NRLs	Max./Min. Luminance (fL)	C_m	CGLW NRLs	Max./Min. Luminance (fL)	C_m	CGLW NRLs
Monitor A	1	14.90 / 8.97	0.248	1.00 **2560**	35.98 / 6.21	0.706	0.354 **5785**	24.97 / 13.13	0.311	0.800 **3200**
	2	28.93 / 2.58	0.836		35.24 / 1.61	0.913		37.30 / 3.32	0.836	
	3	33.65 / 1.12	0.936		37.61 / 1.18	0.939		41.30 / 1.94	0.910	
	4	36.84 / 0.992	0.948		23.68 / 0.75	0.938		42.39 / 1.63	0.926	
Monitor B	1	14.87 / 10.18	0.187	1.11 **2306**	14.16 / 9.60	0.192	1.18 **1736**	14.18 / 10.87	0.132	1.21 **2116**
	2	25.00 / 3.76	0.739		28.57 / 9.33	0.508		21.68 / 4.08	0.683	
	3	34.93 / 1.72	0.906		32.85 / 4.85	0.743		33.67 / 2.22	0.876	
	4	39.37 / 1.02	0.950		34.62 / 2.29	0.876		38.79 / 1.11	0.945	